Development of Modular 3U Form Factor Pulsating Heat Pipe Based Plate Heat Spreader for Electronics Cooling

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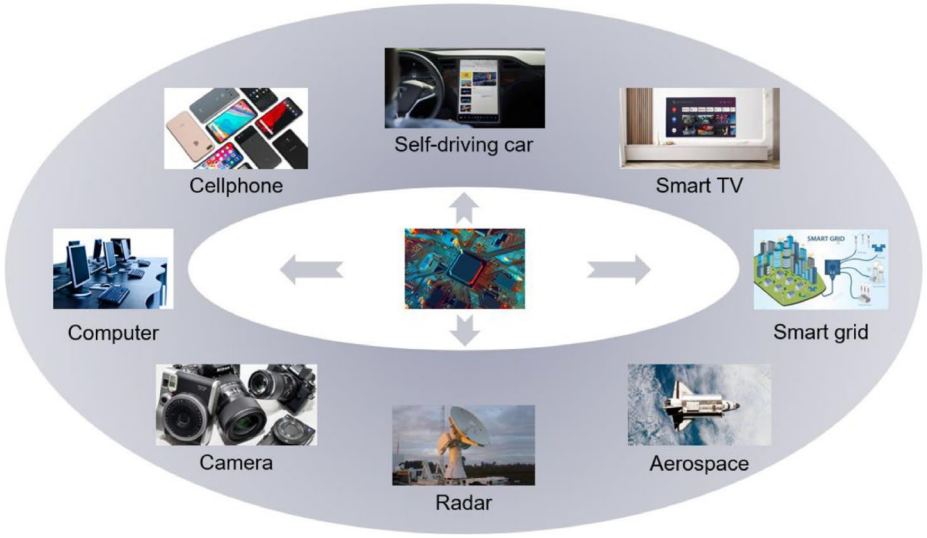
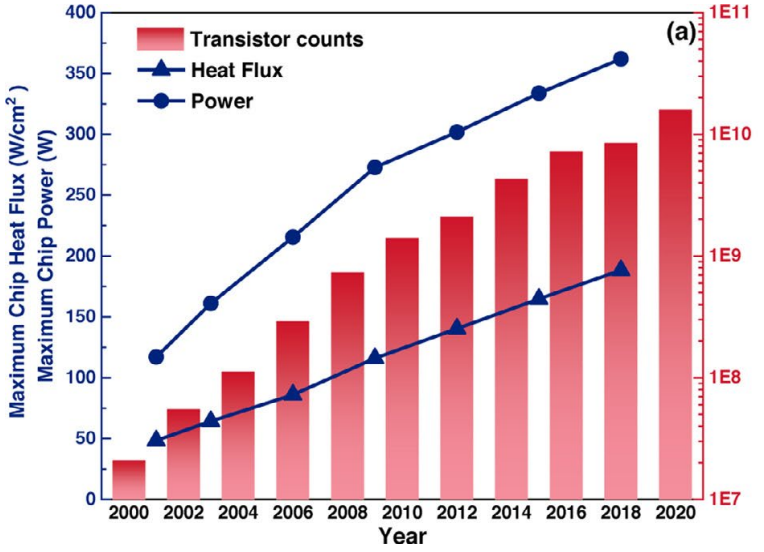
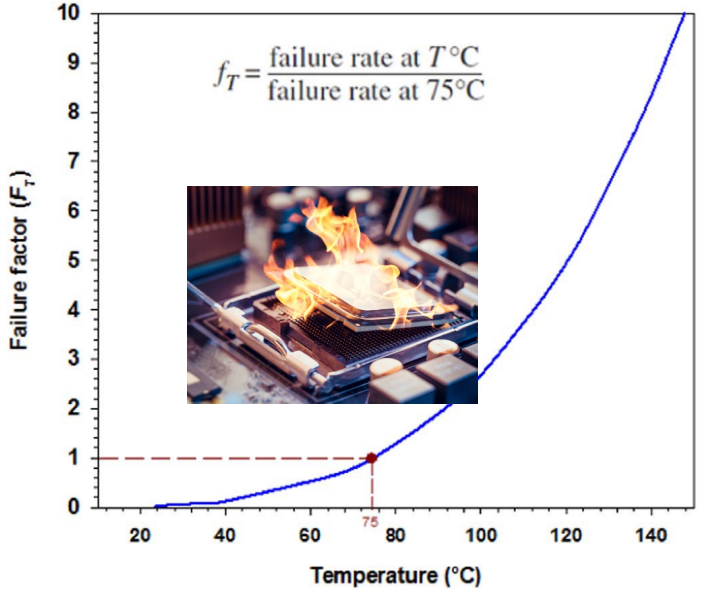
Electronics Waste Heat Management



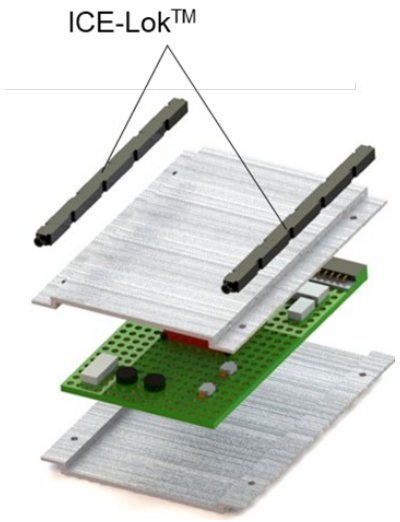


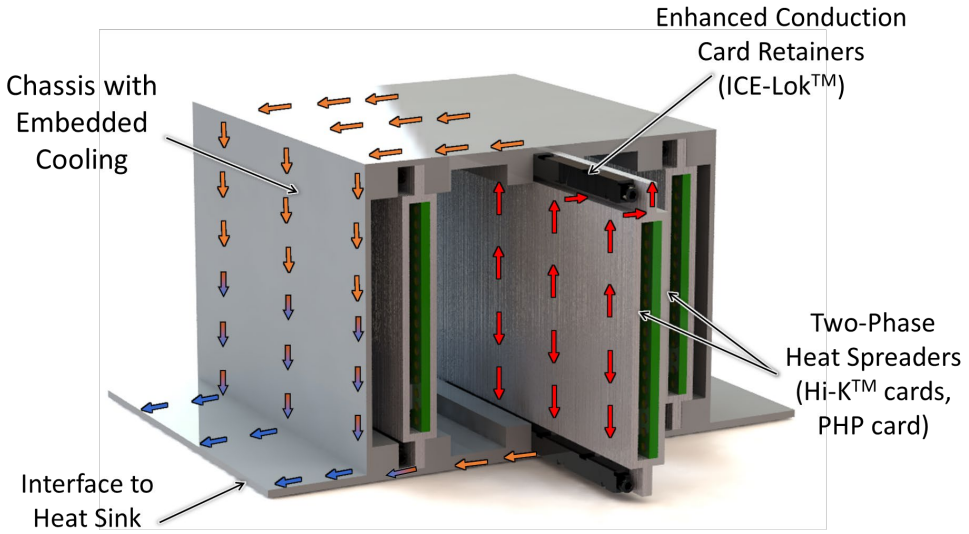


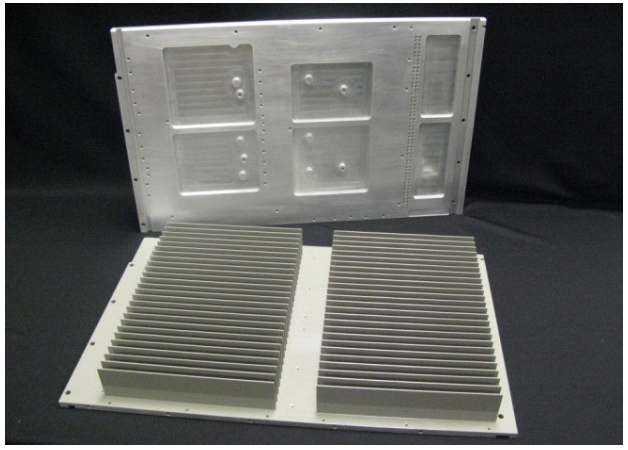
- Shrinking form factor & high compute power → high waste heat flux from electronics
- Electronics cards must be maintained below 75° C to ensure safe & reliable operation
- Traditional approaches employ conduction plates for heat spreading waste-heat dissipation from the electronics
- The material limited thermal conductivity can only make them operable for low heat flux operation
- High heat flux thermal management requires high performance electronics heat spreaders

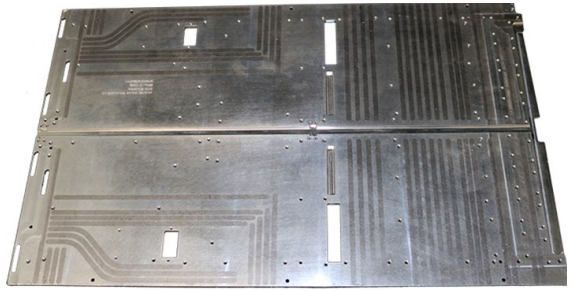
Heat Transfer Devices for Electronics Cooling

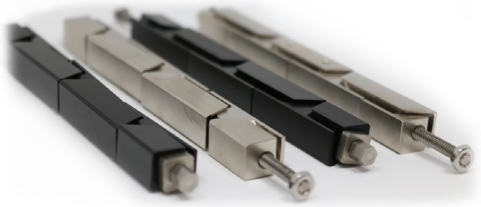
- Electronics heat is rejected from the source to the sink through multiple thermal links
  - Source to thermal spreading plane
  - Electronics enclosure (chassis) card retainer
  - Ultimate heat sink like a cold plate
- ACT's Two-phase Solutions
  - Embedded heat pipe (HiK™ plate)
  - Vapor chambers
  - Pumped-two phase cooling
  - Pulsating heat pipe (R&D)
  - Isothermal Card Edge (ICE-Lok®)

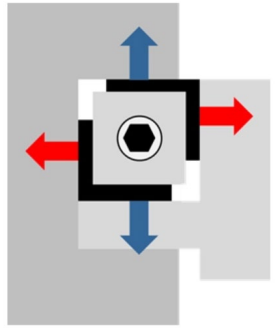






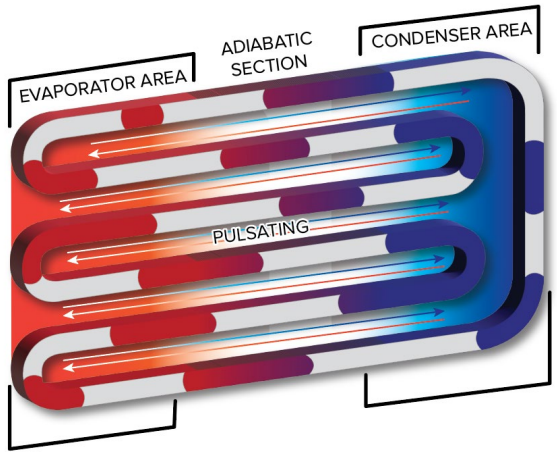






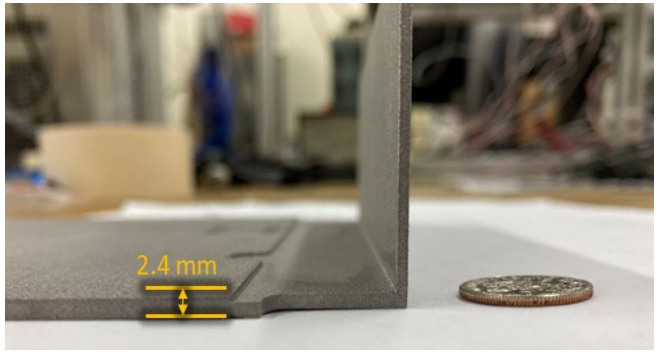
High Performance Heat Spreader: Pulsating Heat Pipe

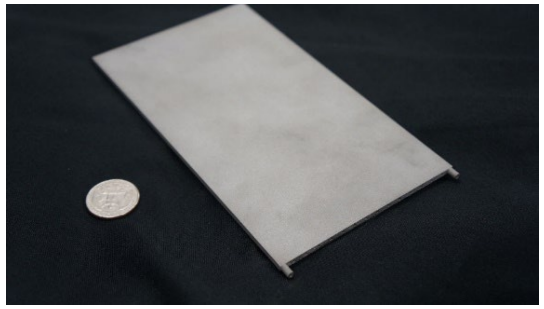
- A Pulsating Heat Pipe (PHP) is a two-phase heat transfer device
- PHP is formed by meandering capillary sized fluid channels, typically connected end-to-end
- When a working fluid is introduced, it naturally distributes into liquid slugs and vapor lungs within the fluid volume

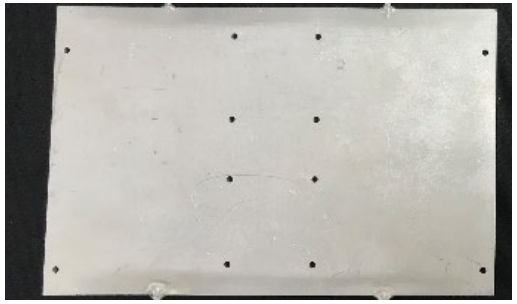


Operating principle

- Heat applied at the receiving section (evaporator) vaporizes the liquid, thereby, increasing the vapor pressure
- Heat delivered at the rejection section (condenser) causes the vapor to shrink or condense, thereby, reducing the vapor pressure
- The driving force ensued from the vapor pressure difference sustained by various hydraulic forces acting on the liquid slug results in the pulsation of the working fluid

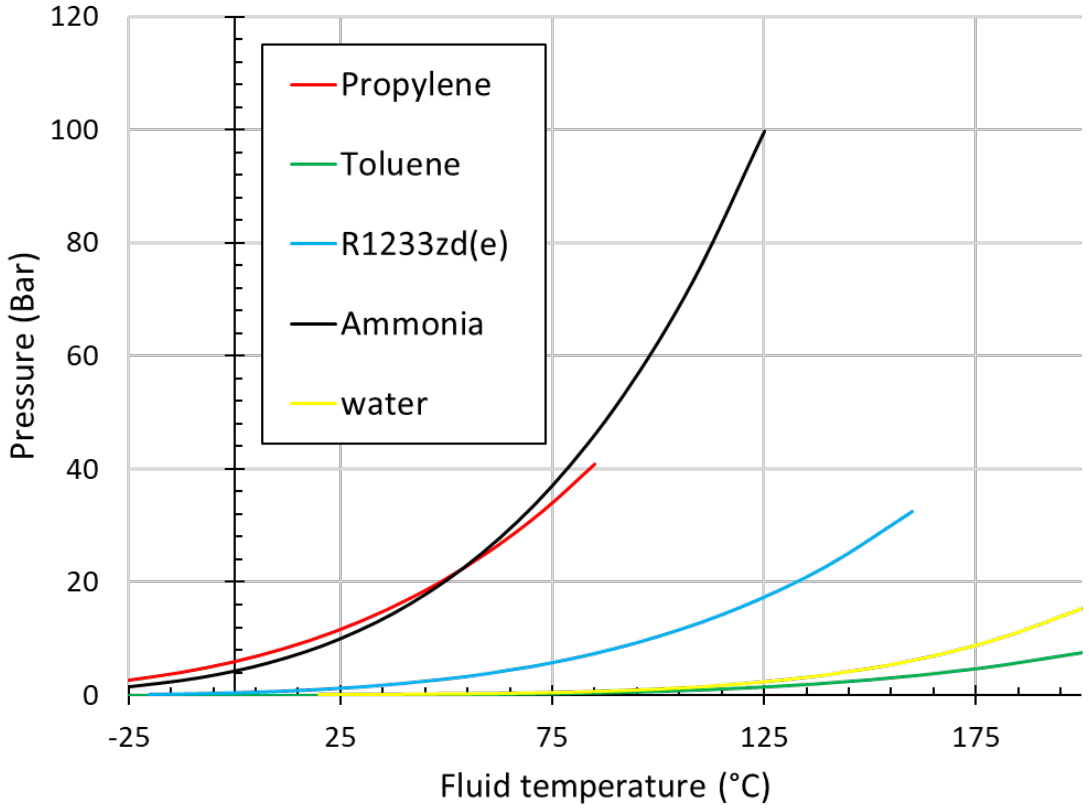


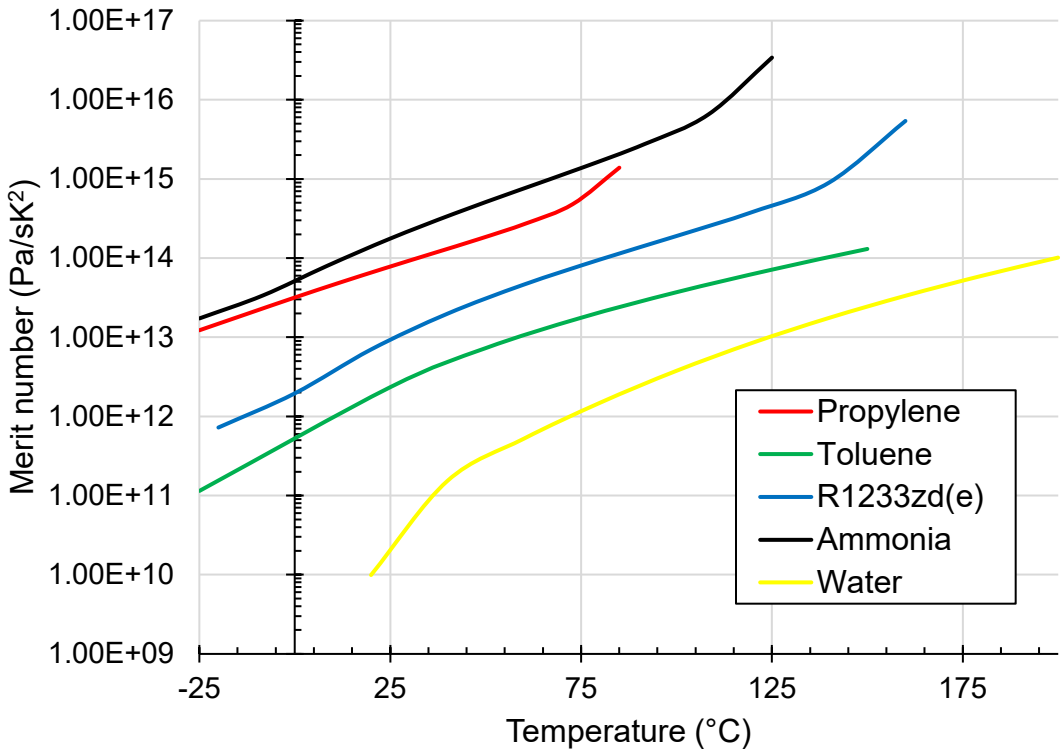




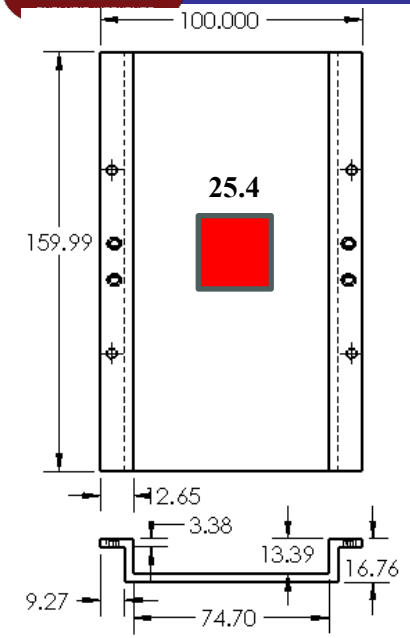
PHP Working Fluid Selection

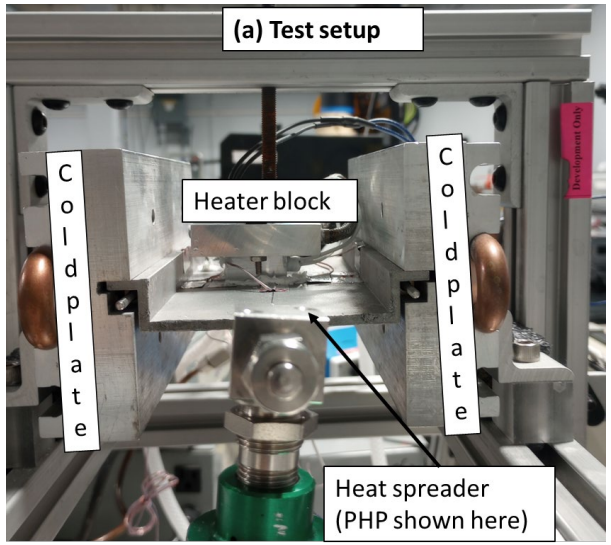
- The pulsation of a working fluid is induced by vapor pressure difference between the evaporator and condenser section
- This is balanced by various hydraulic forces exerted on individual liquid slugs by the vapor and the wall
- Suitable working fluids for electronics cooling applications (up to 80° C): Ammonia, propylene

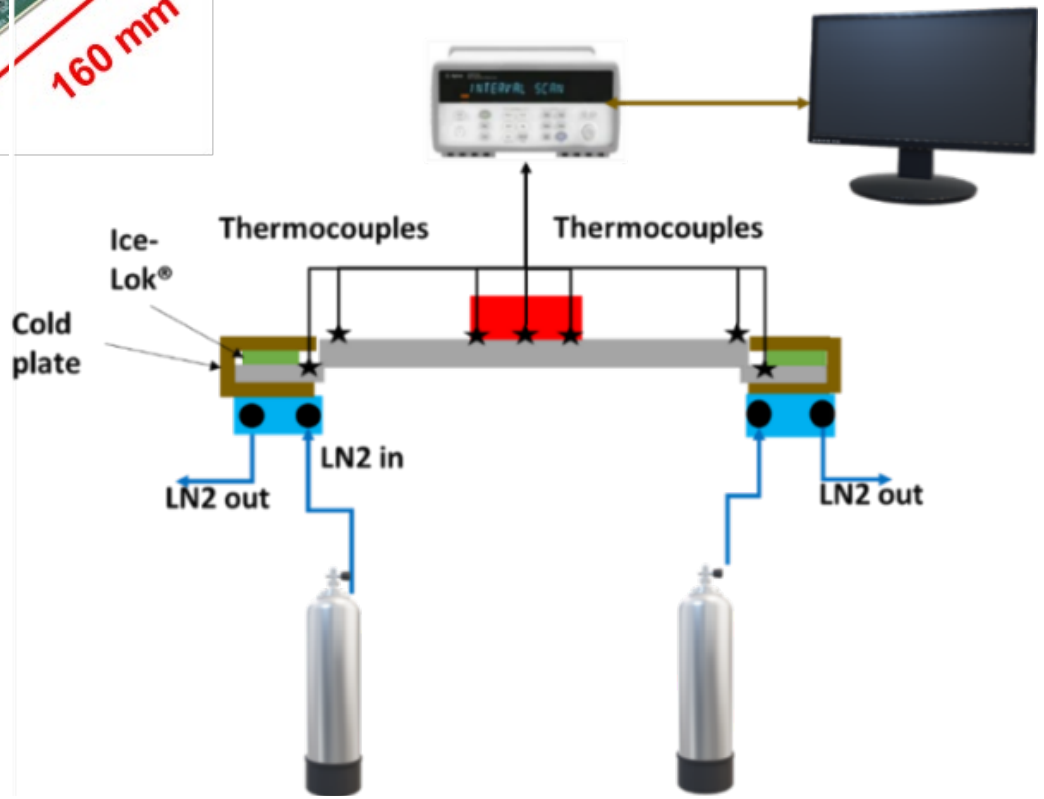




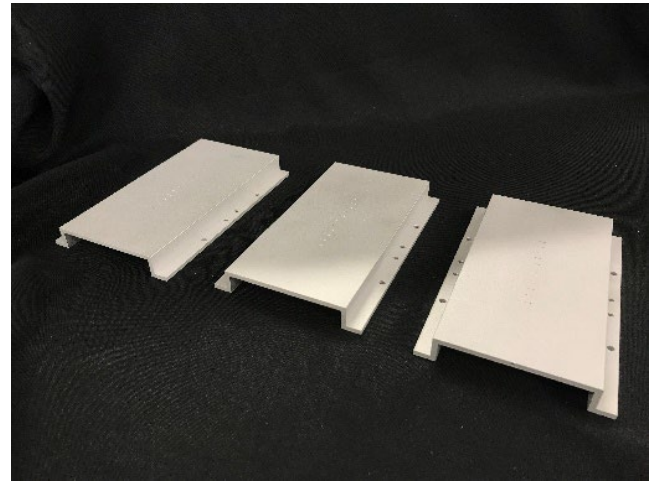
Description of Heat Spreader & Test Methodology



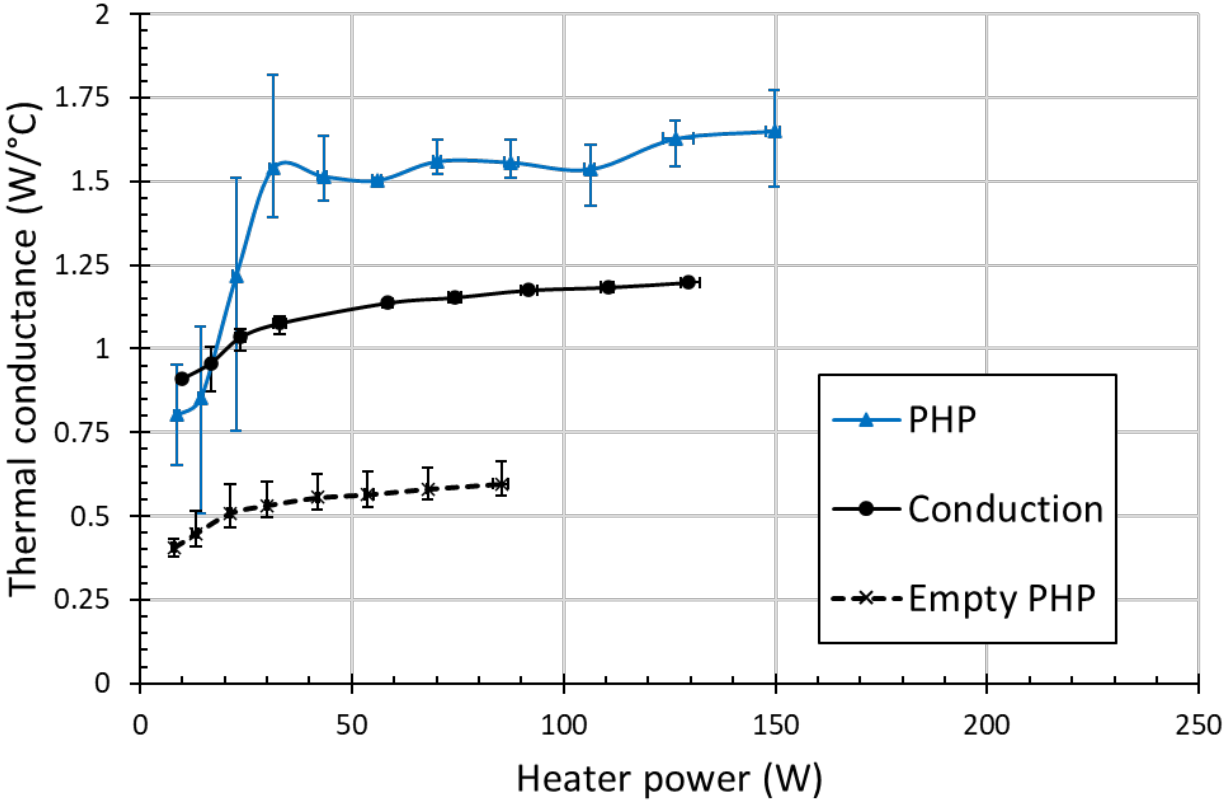


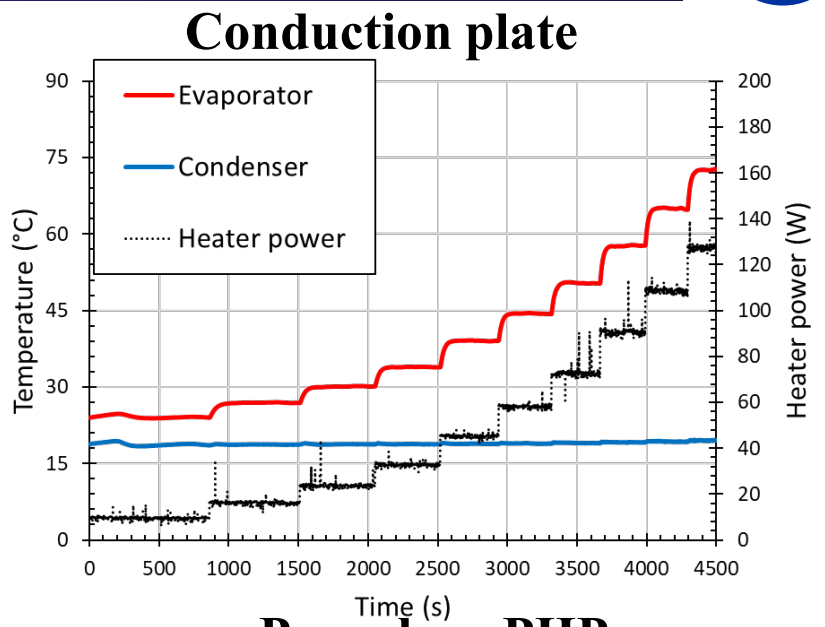


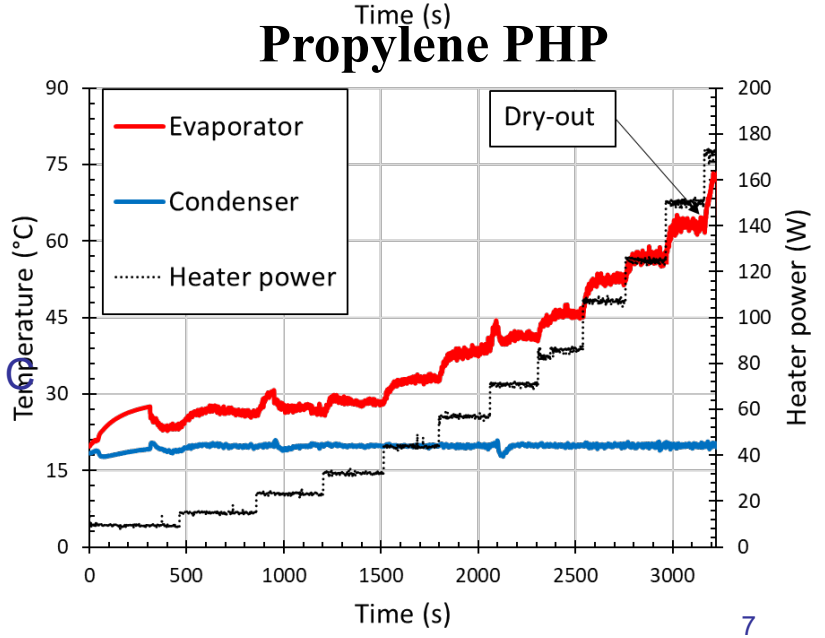
- Geometry: 3U form factor (SpaceVPX compliant)
- Conduction plate heat spreader: CNC machined
- PHP Heat spreader: Additive Manufacturing
- Heat rejection: Cold plates through card retainer
- Condenser section: maintained at constant temperature



PHP (Propylene) vs Conduction Plate

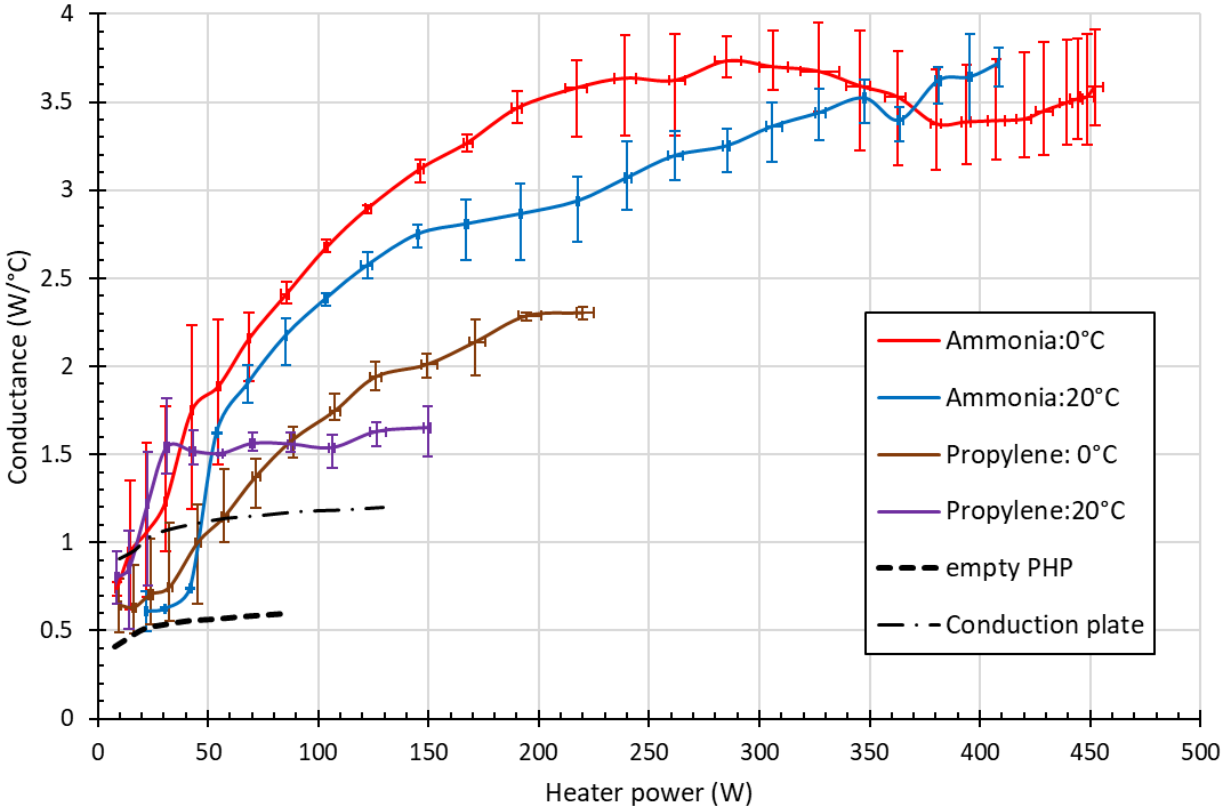






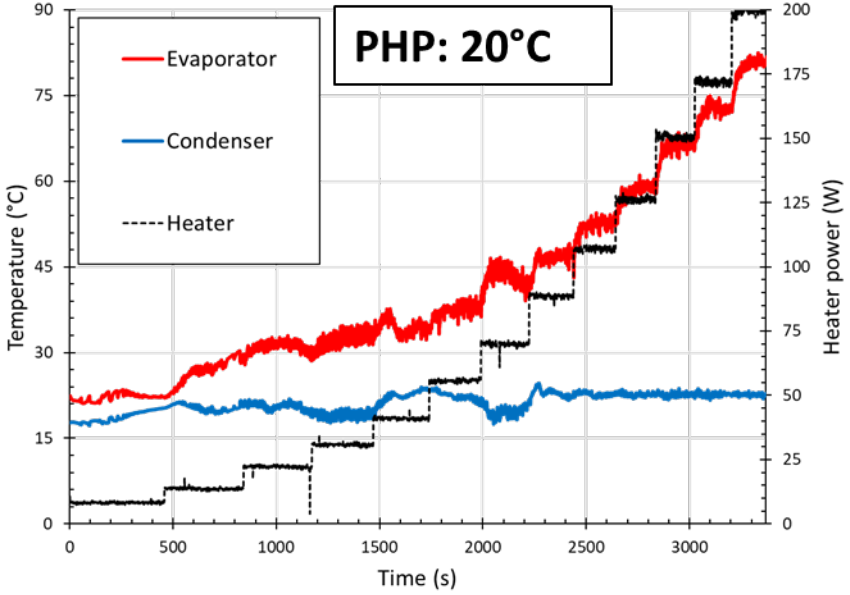
- The thermal conductance of the baseline conduction plate: 1.1±0.1 W/° C
- Thermal conductance of empty PHP (compare PHP performance): 0.55±0.05 W/° C
- Thermal conductance of propylene charged PHP (75% fill ratio): 1.55 W/° C

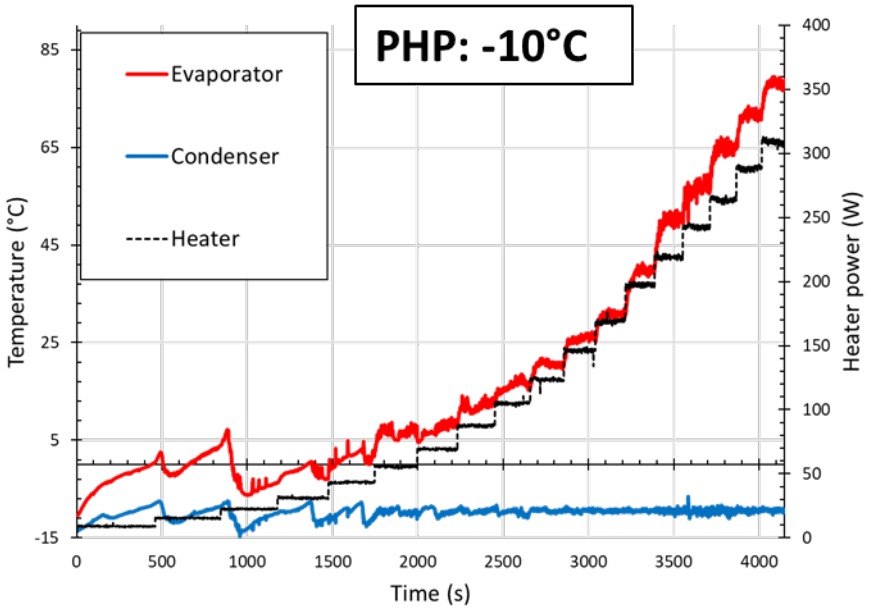
Propylene vs Ammonia PHP

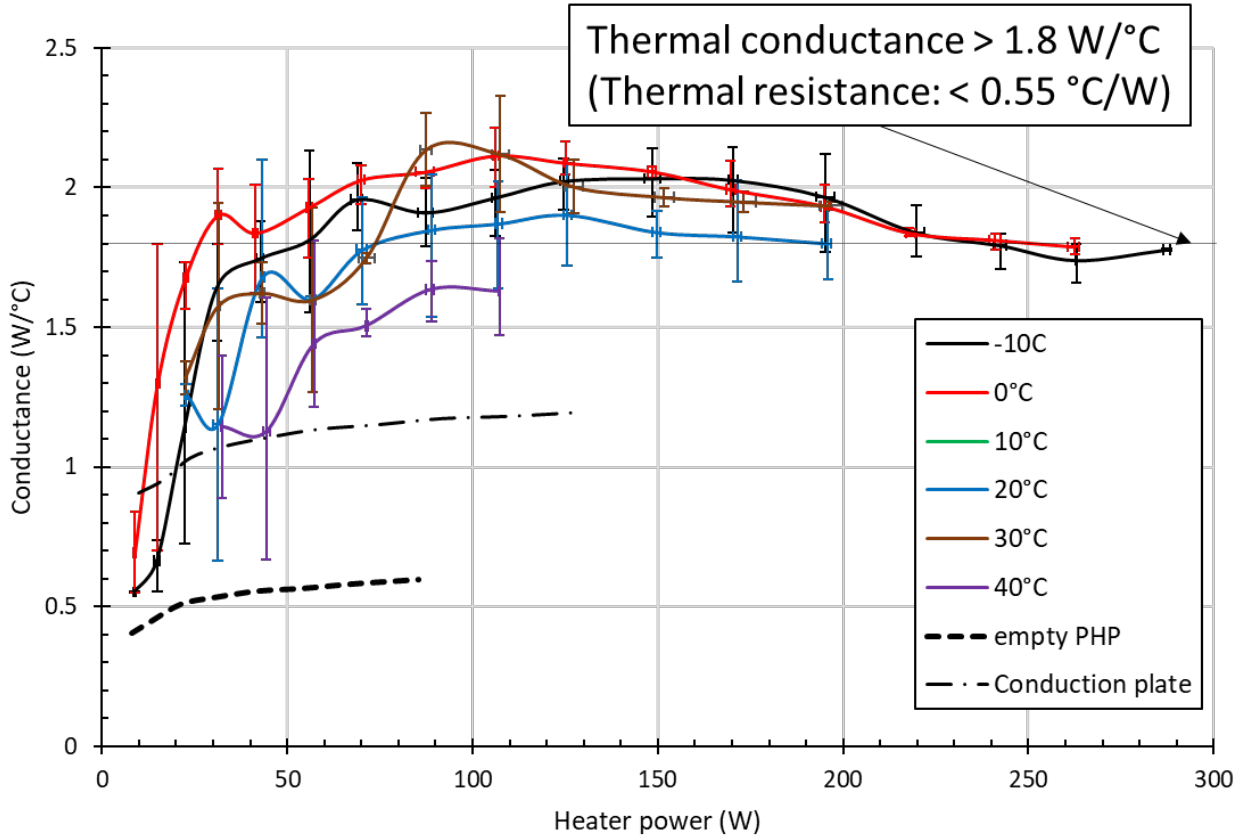


- Fill ratio of 75% compared
- Propylene PHP could deliver up to 220 W heater power at condenser temp of 0°C
- Ammonia PHP could deliver more than 400 W
- High condenser temperature is not favored (following slides)

Ammonia PHP: Influence of Condenser Temperature

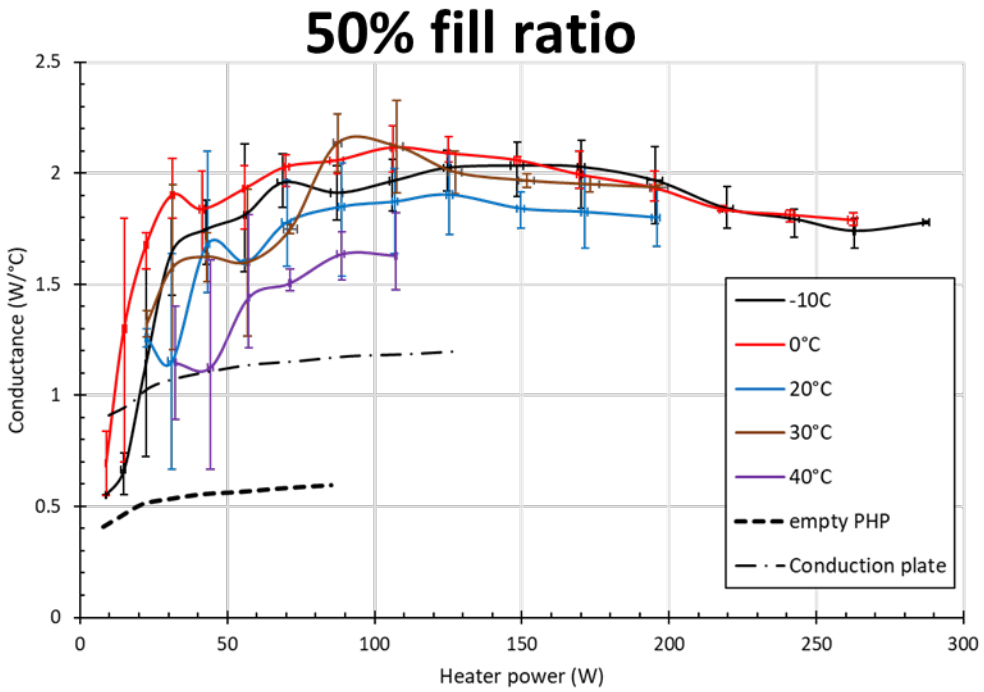


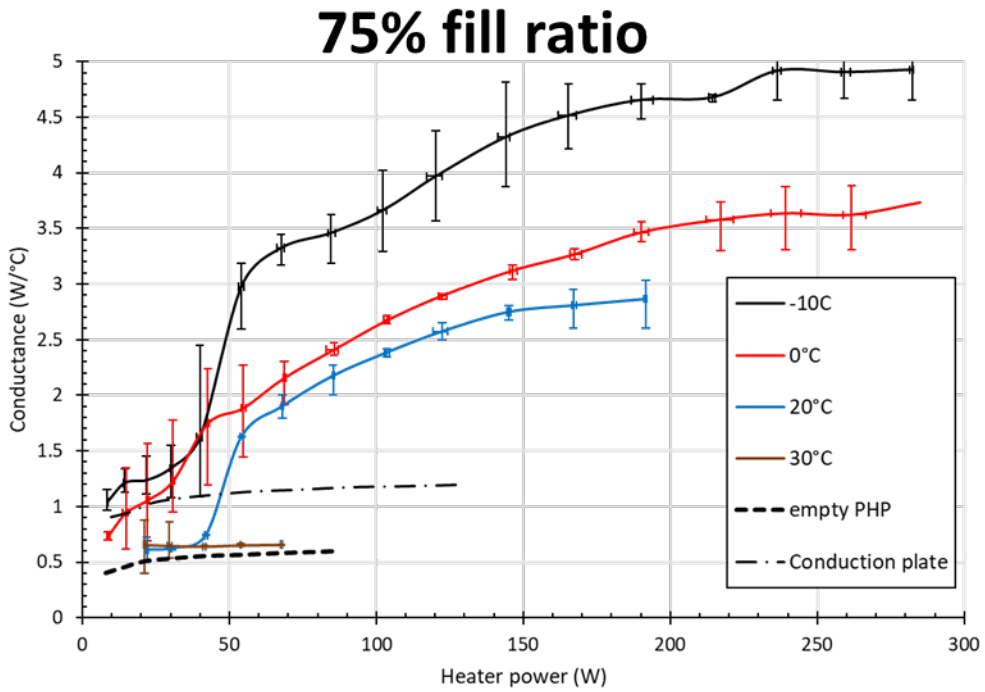




- Fill ratio of 50%
- The thermal conductance showed an increasing trend until heater power in the range 50-100 W
- Peak thermal conductance reached 2 W/ ° C, which was almost 2X conduction plate
- Higher condenser temperature decreased peak performance

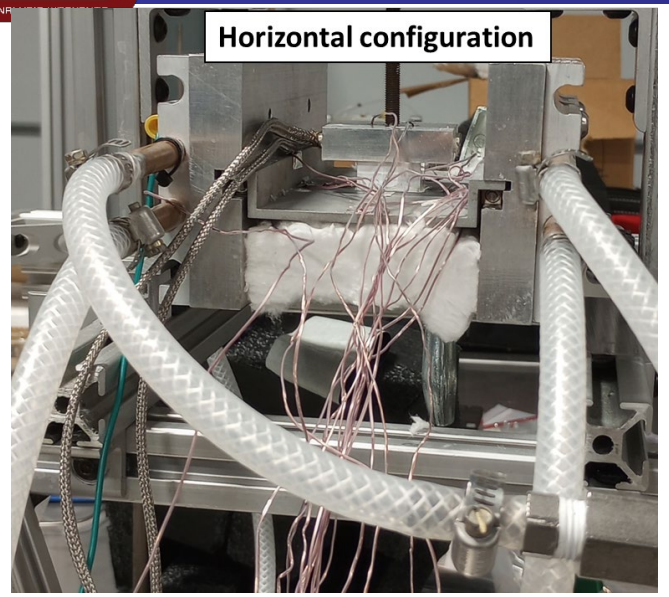
Influence of Fill Ratio on Performance: 50% vs 75%

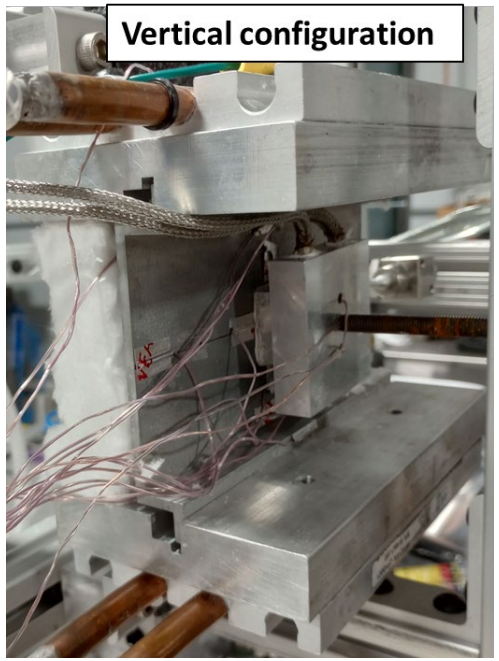


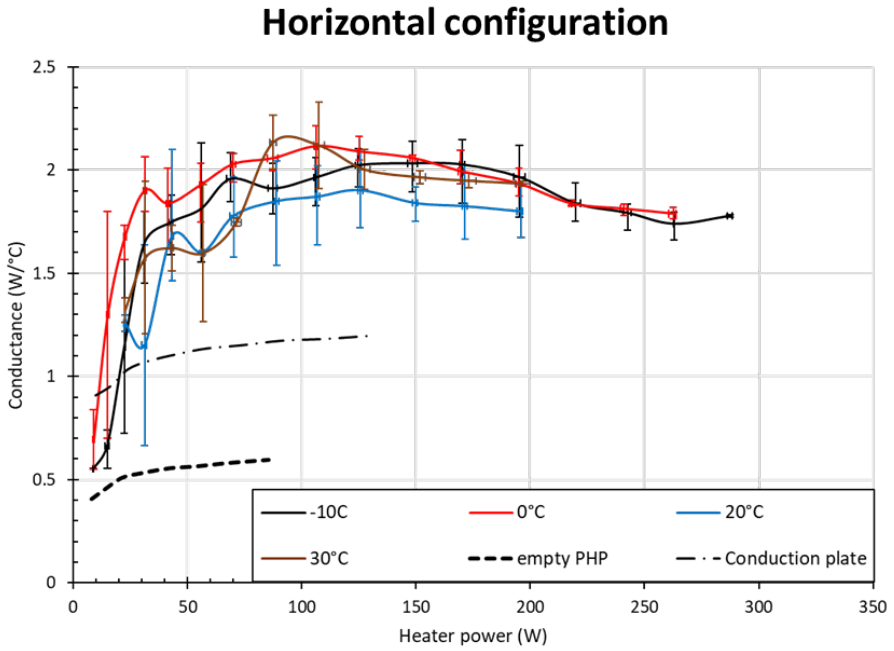


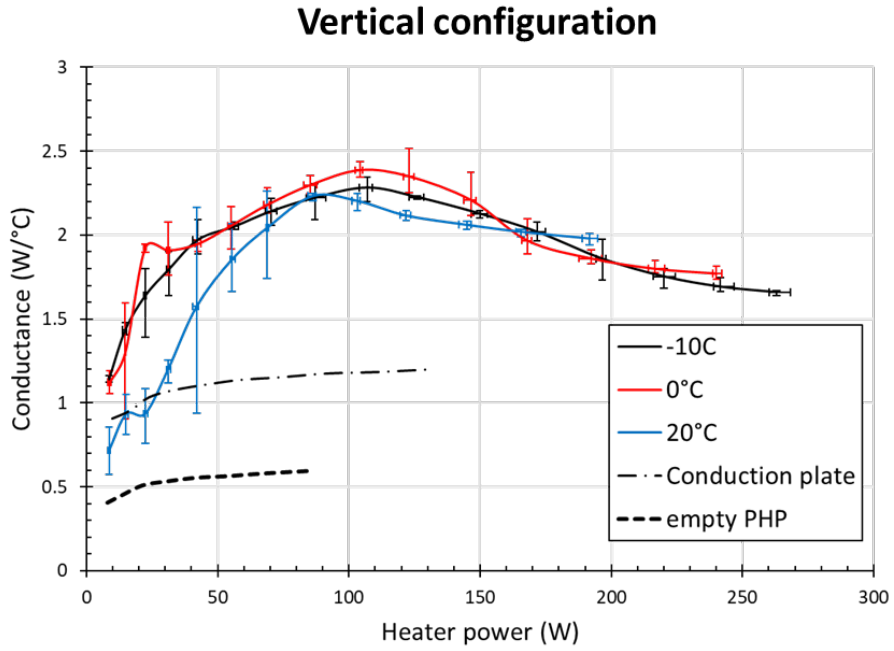
- The thermal conductance of the ammonia PHP at 75% fill ratio showed an increasing trend of thermal conductance, approaching ~ 5 W/° C with condenser at -10° C
- However, the peak thermal conductivity reduced gradually with increasing condenser temperature with 30° C case not working
- In contrast, the ammonia PHP at 50% fill ratio had similar trends for condenser temperatures from -10° C to 30° C
- Ammonia PHP with 50% fill ratio did not operate at 40° C while with 75% fill ratio did not operate at 30° C condenser temperatures respectively

Influence of Orientation on PHP Performance









- The thermal conductance of ammonia PHP in both horizontal and vertical configuration showed similar trend
  - Exception: the vertical configuration showed faster start-up
- In horizontal configuration, the PHP thermal conductance was between 1.8 to 2 W/° C
- In vertical configuration, the PHP thermal conductance reached 2.3 W/° C but reduced to a value around 1.7 W/° C higher heater powers

Summary & Ongoing Activities

- PHP showed significant improvement in thermal conductance compared to conduction plate
- High fluid fill ratio showed gradual improvement in conductance at lower powers
- PHP works better at higher power (if not drying out)
- Propylene PHP could deliver up to 220 W heater power at condenser temp of 0° C
- Ammonia PHP could deliver more than 400 W

Ongoing activities

- 3U PHP Thermal Performance Mapping
- Improve Tools for PHP Design/Model
- Space Qualification

Acknowledgements

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